North American E-Mobility Supply Chain Analysis:

Assessing the North American Supply Chain for Traction Drive Inverters, Motors and Batteries for Class 3-8 Hybrid Electric and Plug-In Electric Commercial Vehicles

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- ✓ This presentation includes interim findings which can change, esp. as market conditions change and new data is developed.

Overview

Timeline

- Start: October 2018
- End: September 2019
- Percent complete in April 2019: 50%

Budget

- Total project funding
  - DOE share: 100%
- Funding received in FY18: $219,959
- Funding received in FY19: $219,959

Barriers

- "Enable reliable hybrid electric, plug-in hybrid and range-extended electric, and battery electric vehicles with performance, safety, and costs comparable to or better than advanced conventional vehicle technologies." (USDRIVE Partnership Goal 1 (Nov. 2016)).
- Accurate information about Electric Passenger and Commercial Vehicles (ECVs) and their component supply chains in North America.
- Actionable intelligence on R&D gaps that affect Autonomous Vehicles (AVs), EVs, Class 3-8 HEV-EVs, PE, batteries and motors in North America.

Partners

Interactions/ collaborations

- Interactions with 100s of primary sources @ OEMs, Tier 1-4s, R&D organizations & Universities.
- US DRIVE Electrical/ Electronics Technical Team members.
- NREL and ORNL (MD-HD EV Assessments)
- Project lead: Synthesis Partners, LLC

Relevance: Progress Toward Objectives

[A] Main focus of this update. [B] On-going FY19 work re: North American (NA) EVSE supply chain analysis.

Overall Objectives (FY19)

- Make public detailed results of FY18 Class 3-8 Medium Duty-Heavy Duty (MD-HD) Hybrid and Electric Vehicle NA Supply Chain Assessment, Covering Producers and Counts of Vehicles, Motors, Inverters and Batteries.
- Assess the NA EV supplier equipment (EVSE) and charging infrastructure supply chain, including Class 1 (AC lower power, 120V), Class 2 (AC higher power, 220-240V), and Class 3 (DC Fast Charge (50-450 kW, up to 800V).
- Share and collaborate with VTO and other USG supply chain assessment activities.

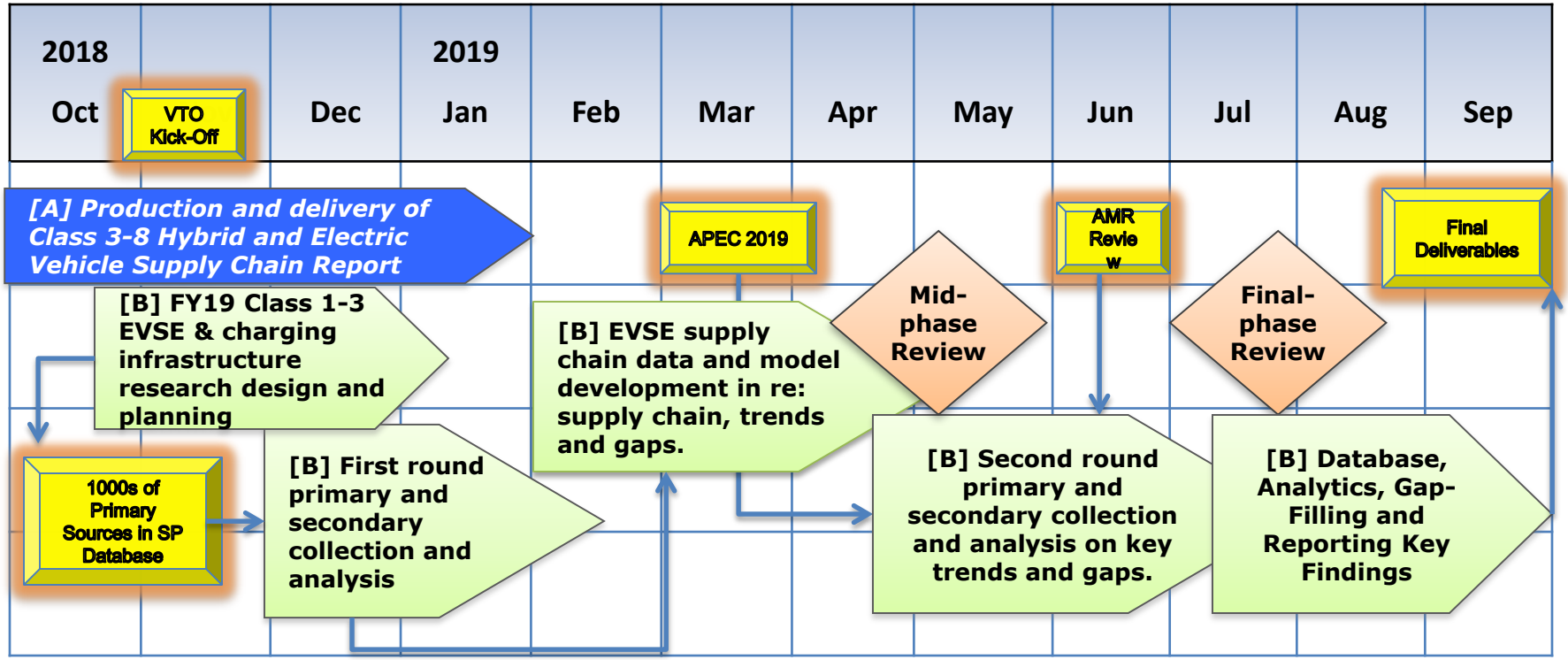
Progress toward objectives during October 2018-April 2019 (date these slides were made)

- Report Issued: "Class 3-8 Hybrid and Electric Vehicles Operating on North American Roads: A Supply Chain Assessment Covering Producers of Vehicles, Drive-Train Motors, Inverters, Converters and Batteries," (cleared for public release April 2019).
- 50% of NA EVSE and charging infrastructure assessment complete, including 360+ individuals and 140+ organizations identified and in process of contacting.
- Primary source research being integrated into emerging NA EVSE and Charging Infrastructure database (30% complete).

Impact in FY19

- First independent assessment of actual number and types of Class 3-8 hybrid and electric vehicles operating on North American roads in 2018.
- VTO decision support based on up-to-date original, validated, quantified information regarding Class 3-8 HEV and EVs operating on NA roads.
- Monthly detailed updates to VTO regarding developments in the Class 1-3 NA EVSE and EV charging infrastructure research, including key player technology and business model information.

Project Milestones

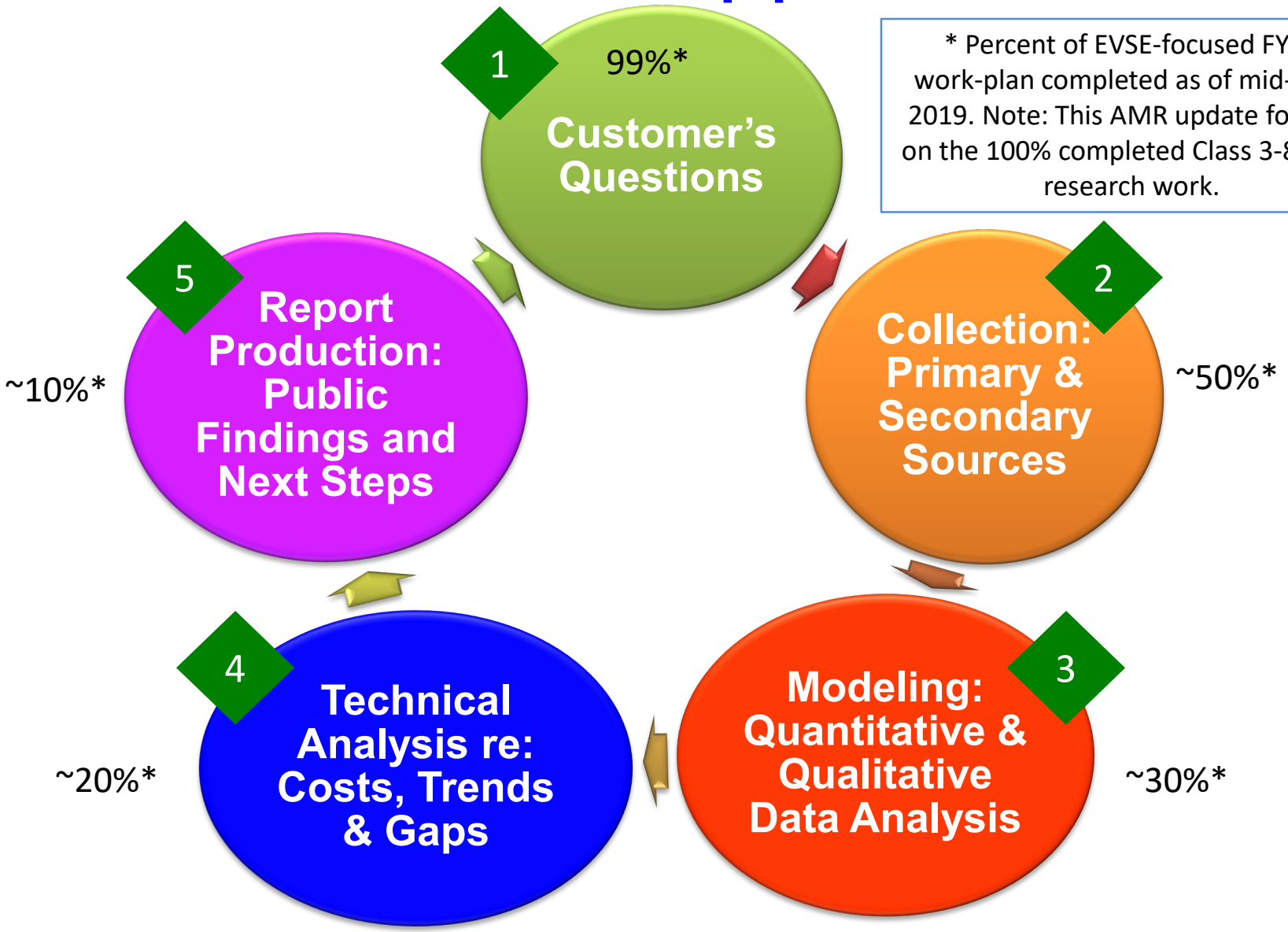


Go No/Go Decision Points: Ongoing assessment, **mid- and end-of-phase review.**

Challenges/Barriers: **Time to process and analyze large amounts of heterogeneous data**; accessibility of primary sources both in-person and electronically; navigation to highest-value data via source confidentiality agreements; opportunities to drill-down with SMEs on specific R&D gaps.

Key Deliverables: **Monthly VTO updates,** Presentations, data-sets and public reports on key findings.

Technical Approach



* Percent of EVSE-focused FY19 work-plan completed as of mid-April 2019. Note: This AMR update focuses on the 100% completed Class 3-8 FY18 research work.

Technical Approach Details

- **[A] Focus today:** Detailed findings regarding North American Class 3-8 Hybrid and Electric Vehicle Supply Chain. [Public Report available.]

- **[B] Ongoing work: Jan. – Sept. 2019: Primary and secondary source research to produce quantitative and qualitative data on NA EVSE and charging infrastructure participants, including:**
  i. EVSE players and their equipment types.
  ii. Characterize EVSE players by revenue, technology, business model and 5-year plans.
  iii. EV charging infrastructure players and their networks.
  iv. Characterize charging infrastructure players by revenue, technology, business model and 5-year plans.
  v. Assessment of gaps, trends and key barriers, including in re: (e.g.) power level issues; siting decisions; business model issues; or other gaps.

- **Integrated Impact:** Research and reporting actionable information regarding:
  i. Current baseline re: Class 3-8s HEV and EVs Operating on NA roads, their suppliers, and numbers and types of NA EV charging infrastructure players.
  ii. Key player statements about plans, gaps, constraints and bottlenecks in the NA supply chain for Class 3-8 HEV and EVs, and EV charging infrastructure.

Technical Accomplishments

1. *[A] FY18: "Class 3-8 Hybrid and Electric Vehicles Operating on North American Roads: A Supply Chain Assessment Covering Producers of Vehicles, Drive-Train Motors, Inverters, Converters and Batteries," (completed January 2019).*
   - ✓ ***First comprehensive public Class 3-8 HEV and EV count and NA supply chain gap assessment.***

2. *[B] FY19: Ongoing NA EV charging infrastructure assessment: January through mid-April 2019:*
   - ✓ Collected 50% of total information we expect to collect; gap-analysis data pending.
   - ✓ Inputted and modeled approximately 30% of the collected information into an emerging database of Class 1-3 EVSE and EV charging infrastructure suppliers in NA.
   - ✓ Per Technical Approach Step #4: Analysis 20% complete.
   - ✓ Per Technical Approach Step #5: Report production phase just beginning.
   - ✓ 250+ NA EV charging collection phone calls made and e-mails executed thru March 2019.
   - ✓ 1,000+ NA EV charging electronic sources reviewed thru March 2019.
   - ✓ 360+ individuals and 140+ organizations identified as having relevant experience or information regarding NA EV charging infrastructure and EVSEs thru March 2019.

Class 3-8 HEV and EV Key Findings:

First publicly available vehicle count baseline.

- Approximate total number of class 3-8 HEV and EVs in operation on NA roads in 2018:
  - Trucks: 11,909
  - Buses: 13,826
  - Up-Fitted: 3,187
  - ***Estimated subtotal in operation on NA roads based on above: 28,922.***

- Approximate total number of class 3-8 HEV and EVs in operation globally* in 2018 based on our NA-based research re: major component suppliers (many of which do not provide public data for NA-only and report global sales):
  - Motor Drive Suppliers vehicle count: 47,404
  - Battery Supplier vehicle count: 32,381
  - Inverter/Converter Supplier vehicle count: 38,071
  - ***Estimated subtotal in operation globally based on average from above: 39,285.***

- *Notes:*
  - *"In operation on NA roads" and "in operation globally" are not always mutually exclusive categories because there is overlap in information reported from suppliers.*
  - **Global counts are estimates based necessarily on NA focused supplier research only. This project focused on the NA supply chain and all global numbers are provided only as a starting point for further discussion.*

Class 3-8 HEV and EV Key Findings:

In-depth NA Supply Chain Gap Analysis (1)

- Percent distribution of gap statements relevant to Class 3-8 HEV and EVs in NA, from 100s of gap statements, obtained through open-ended interviews from 2013-July 30, 2018*:
  - Battery: 45%
  - Inverter: 31%
  - Motor: 29%
  - Other**: 27%
  - Converter: 12%

**Percentages do not add up to 100 because source statements can address more than one gap. Goal: Every instance of any one issue regarding a constraint or bottleneck in the NA supply chain that was raised by a source is counted as a gap.*

*** Other covers manufacturability, public incentives and subsidies, regulation, standards, materials and software.*

Class 3-8 HEV and EV Key Findings:

In-depth NA Supply Chain Gap Analysis (2)

- Battery gap statement analysis:
  - 51 relate to Other*
  - 41 relate to Engineering;
  - 37 relate to Costs;
  - 25 relate to Materials;
  - 17 relate to Standards; and
  - 6 relate to Software.

177 gap statements

- Motor gap statement analysis:
  - 19 relate to Engineering
  - 17 relate to Costs;
  - 15 relate to Other;
  - 7 relate to Standards;
  - 6 relate to Materials; and
  - 6 relate to Software.

70 gap statements

- Inverter gap statement analysis:
  - 27 relate to Other*
  - 13 relate to Engineering;
  - 8 relate to Costs;
  - 8 relate to Standards;
  - 7 relate to Software; and
  - 2 relate to Materials.

65 gap statements

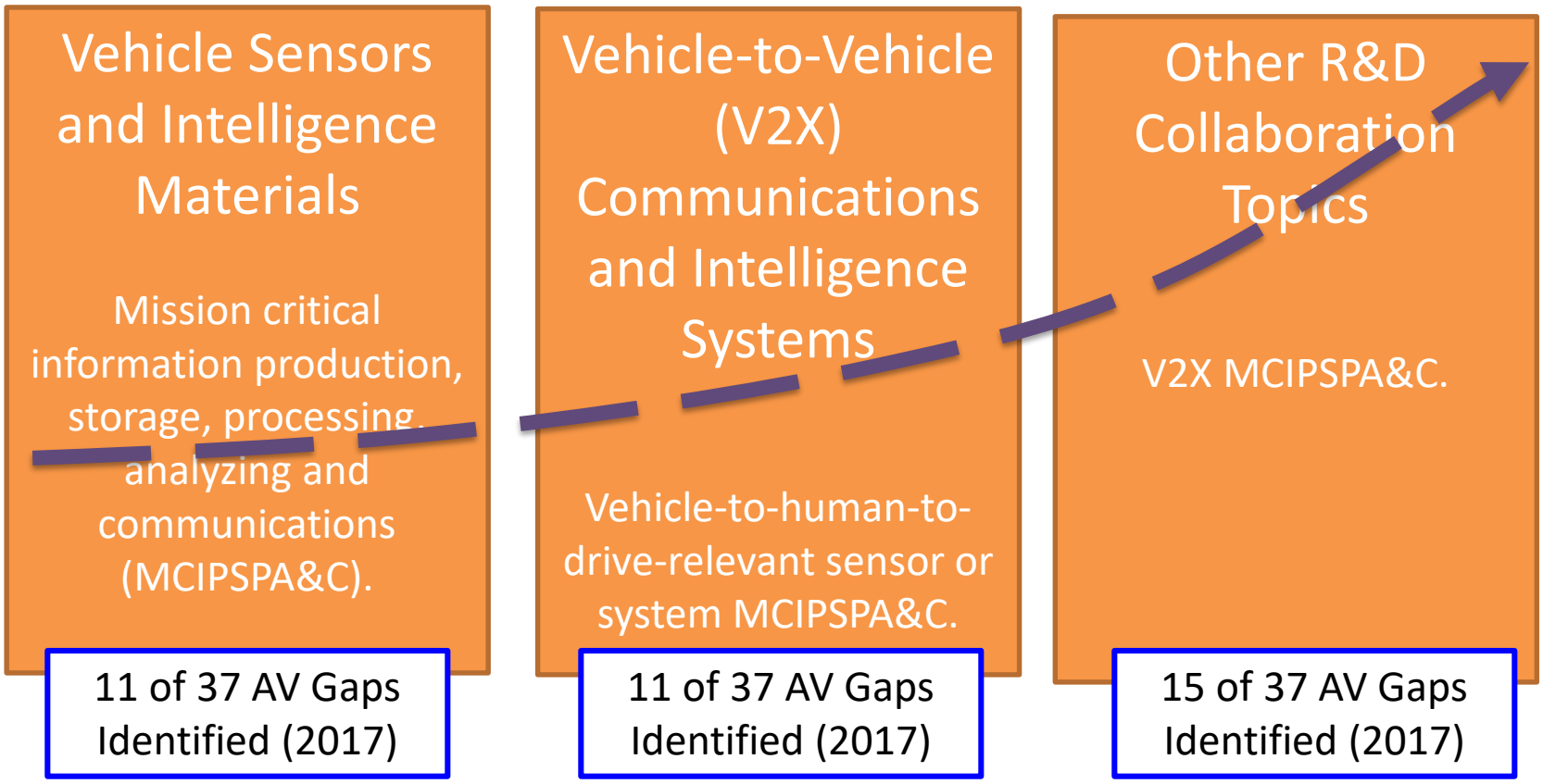
- Converter gap statement analysis:
  - 10 relate to Engineering
  - 10 relate to Other;
  - 6 relate to Standards;
  - 5 relate to Software;
  - 4 relate to Costs; and
  - 0 relate to Materials.

35 gap statements

** Other covers public incentives, subsidies and regulation among other cross-disciplinary topics.*

Source: SP analysis of 100s of gap statements relevant to Class 3-8 HEV and EVs developed through customized, open-ended interviews conducted from 2013 to July 2018.

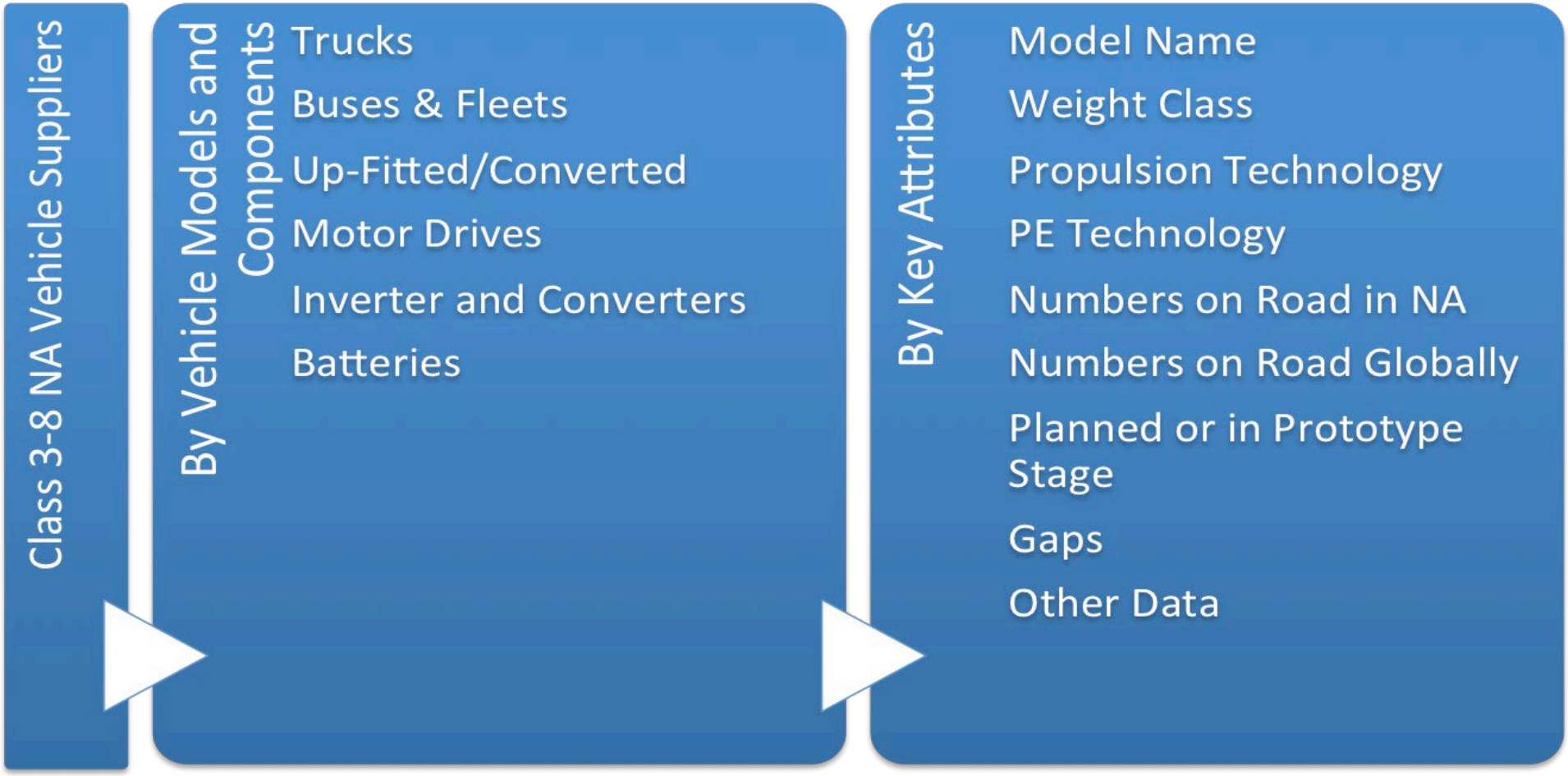
Technology Gaps Require Increasingly Interdisciplinary RDT&E



Hardware … → Hardcoded Hardware Accelerators for Software … → Software

Connecting the dots: Gap analysis 2017 (AVs); Gap Analysis 2018 (Class 3-8 xEVs) and pending, Gap Analysis 2019 (EVSEs).

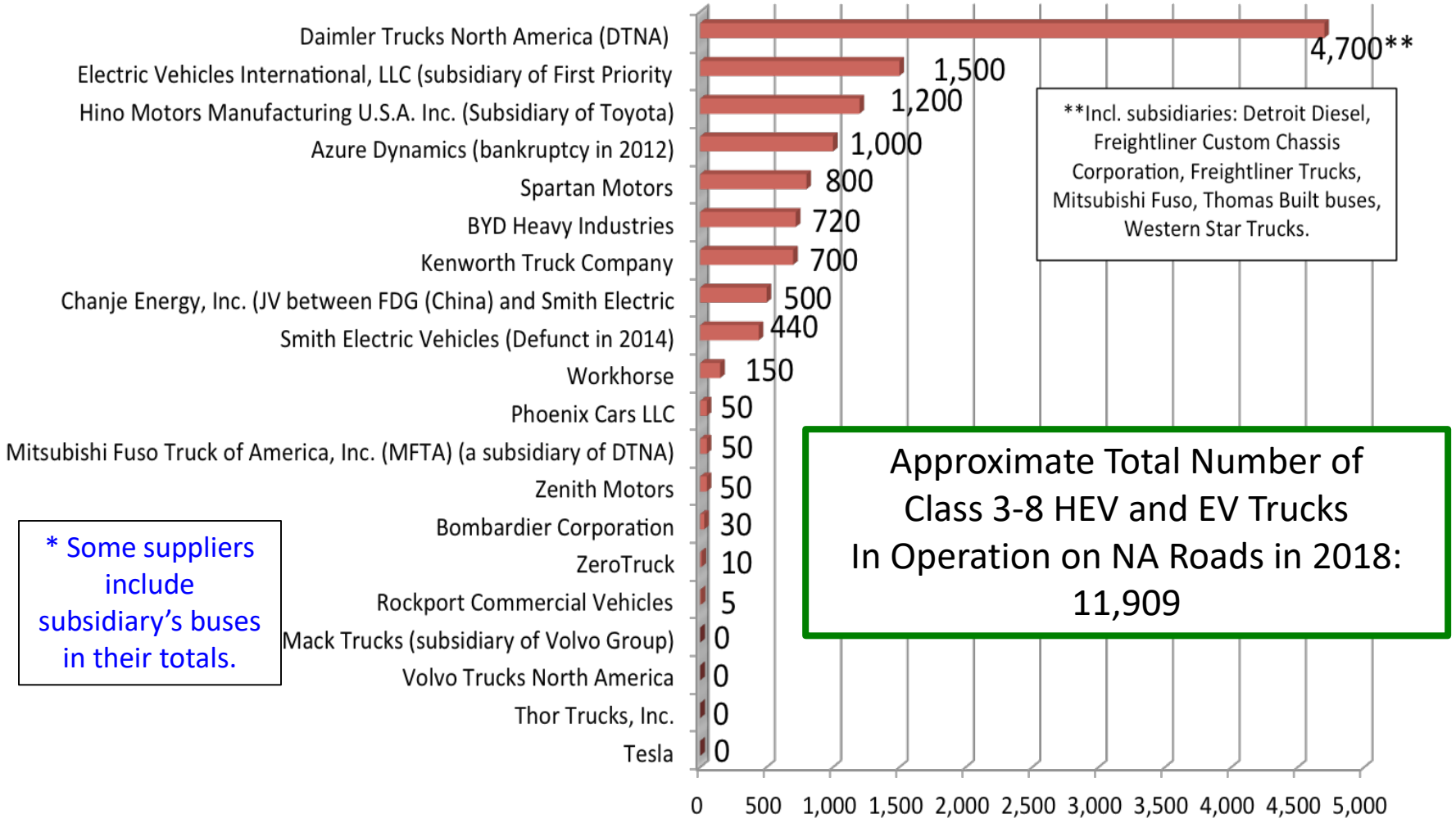
Class 3-8 Hybrid and Electric Commercial Vehicle Database*



* Database is employed for internal work-flow and includes proprietary source information.

Approximate Number of Class 3-8 HEV & EV Trucks* Operating on NA Roads in 2018, by Supplier

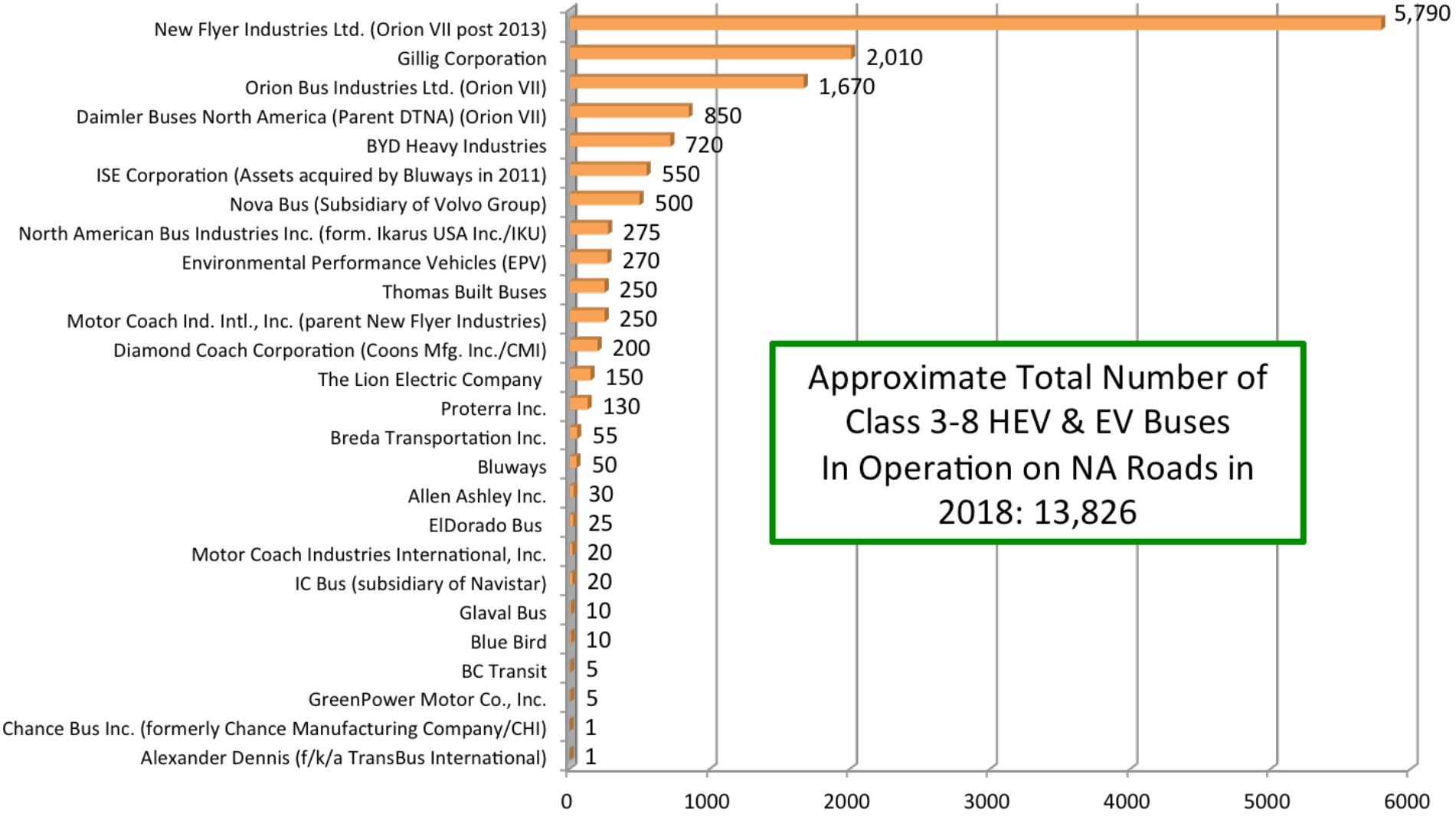
(Aggregated across models; rounded #s; does not include prototypes.)



* Some suppliers include subsidiary's buses in their totals.

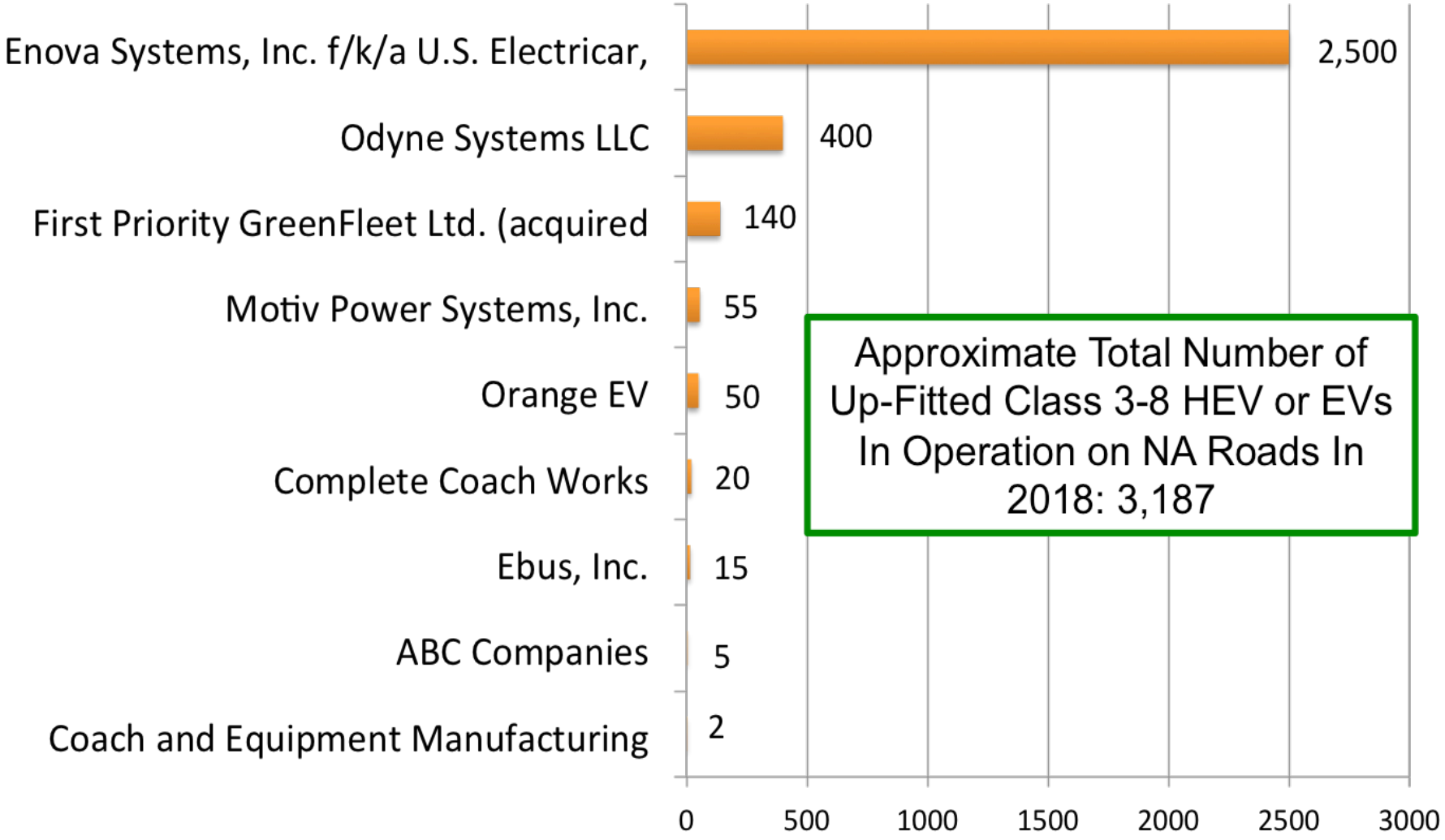
Approximate Number of Class 3-8 HEV & EV Buses Operating on NA Roads in 2018, by Supplier

(Aggregated across models; rounded #s; does not include prototypes.)



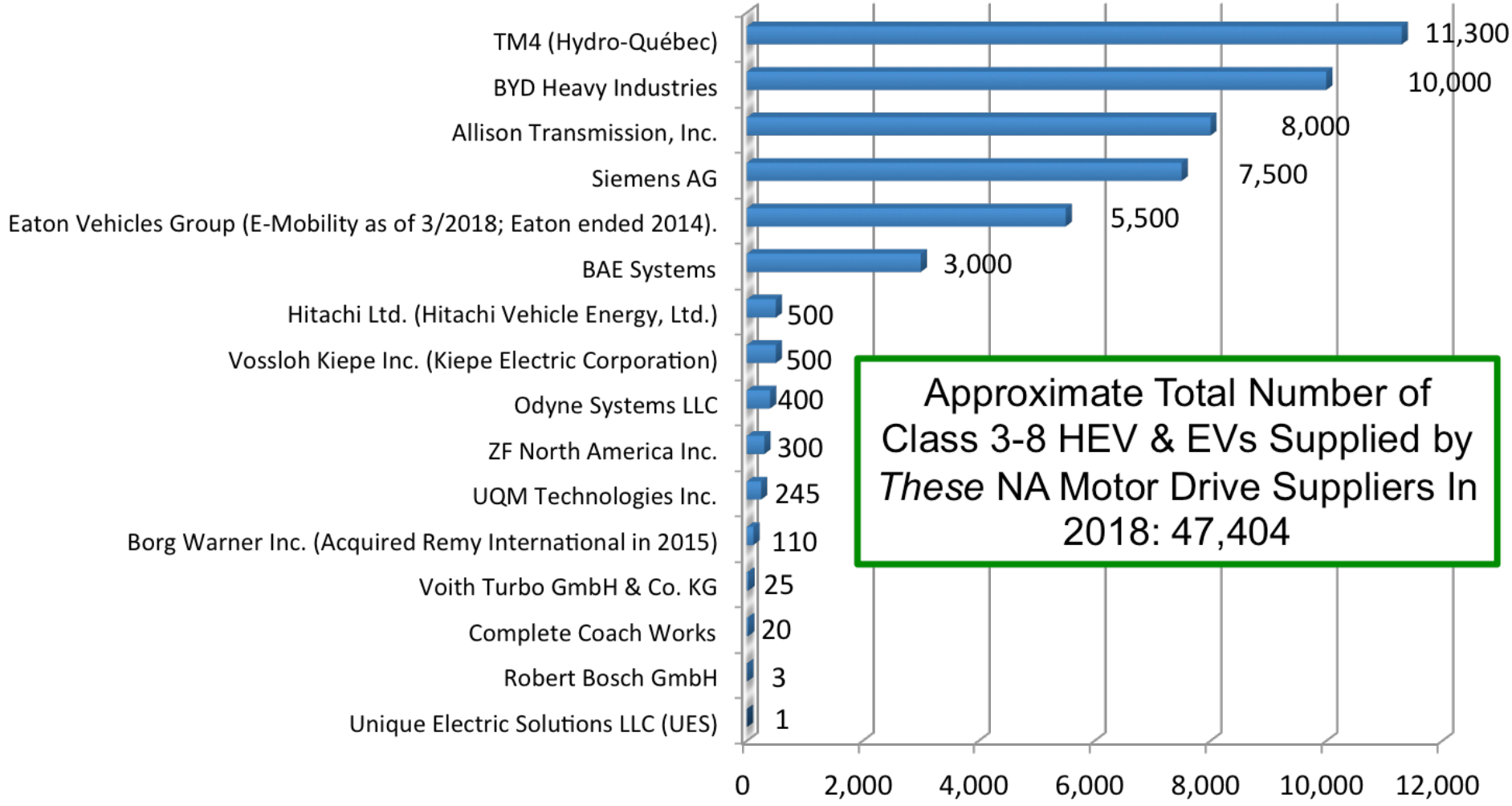
Approximate Number of Class 3-8 Up-Fitted HEV & EVs Operating on NA Roads in 2018, by Supplier

(Aggregated across models; Rounded #s; Does not include prototypes.)

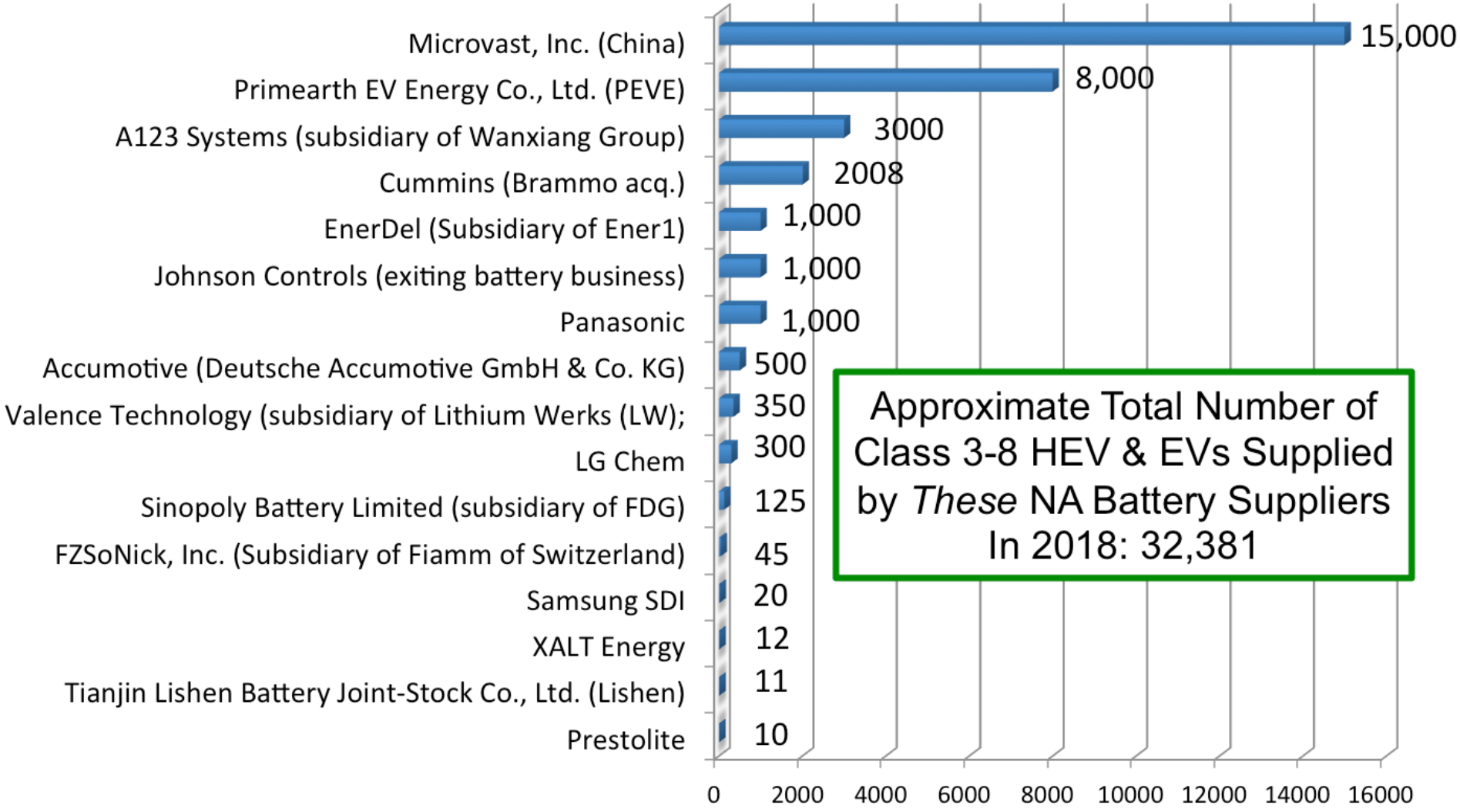


Approximate Number of Class 3-8 HEV & EVs Supplied by NA Motor Drive Suppliers in 2018

(Rounded #s; based on NA focused supplier research only.)

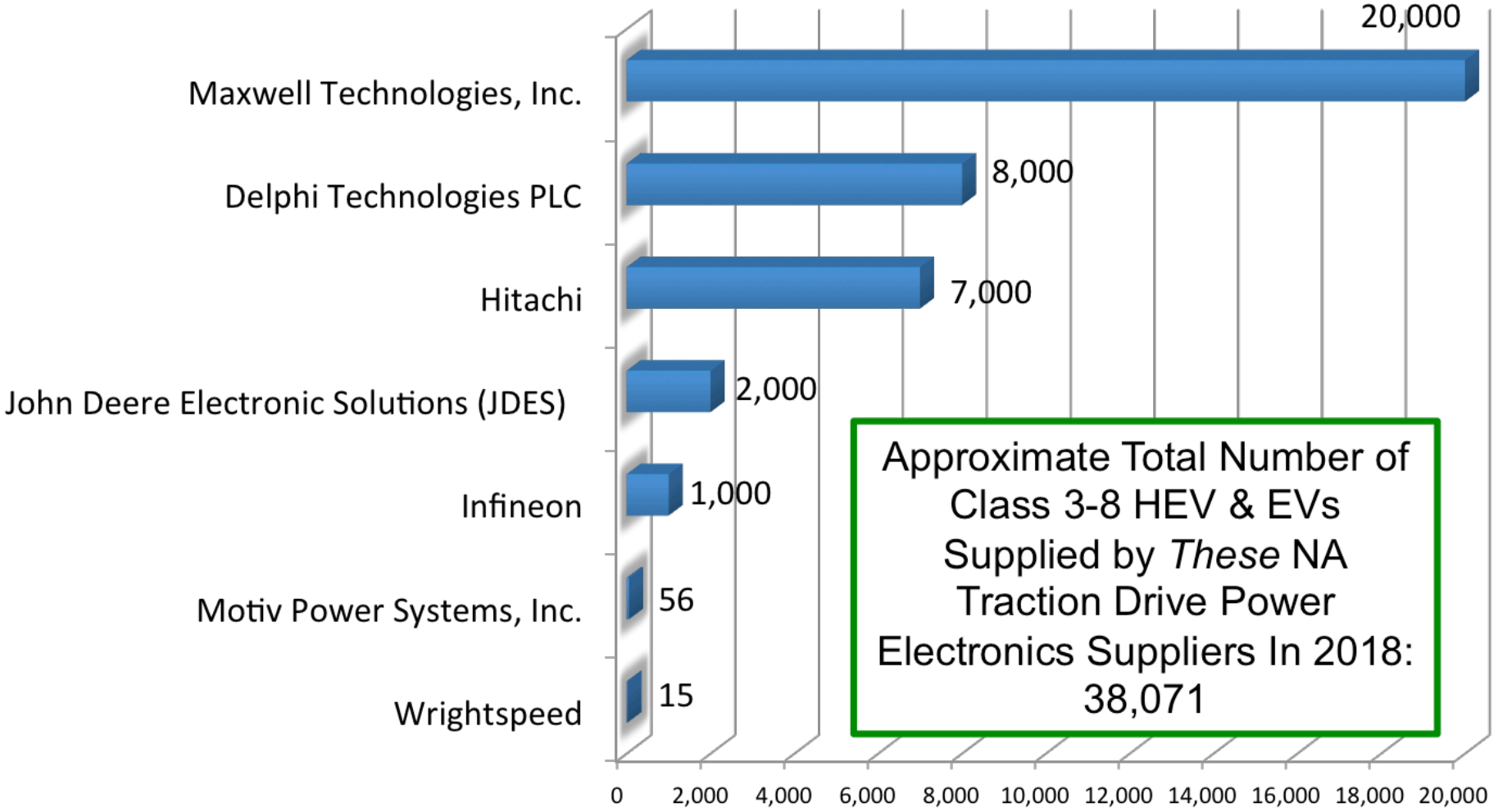


Approximate Number of Class 3-8 HEV & EVs Supplied by NA Battery Suppliers in 2018



Approximate Number of Class 3-8 HEV & EVs Supplied by NA Inverter, Converter and other Traction Drive PE Component Suppliers in 2018

(Rounded #s; based on NA focused supplier research only.)



Sample Class 3-8 Database Drill-Down

- Example: A123 (Livonia, MI)
  - *Selected components supplied:* Lithium Ion-Nickel Manganese Cobalt battery; Lithium Ion Cylindrical and Prismatic Cell Battery Packs
  - *Class 3-8 applications:* New Flyer Xcelsior XE40 Bus; BAE Systems HybriDrive Series Propulsion System; Navistar E-Star Class 3 (model in service 2010-2013); Orion VII Hybrid Electric Bus (in service since 2007); Smith Electric Class 5-7 Newton electric truck.

- Example: Allison Transmission (Indianapolis, IN)
  - *Selected components supplied:* Traction driver inverter; Allison H40/50 EP (both generator and motor).
  - *Class 3-8 Applications:* Gillig Low Floor BRT Bus (Allison EP 40/H 40 EP) (2004-present); Gillig Low Floor BRT Trolley Bus (Allison Parallel diesel-electric hybrid powertrain); Nova LFS HEV bus (H40 EP); Nova LFS Arctic HEV (H50 EP); Motor Coach Industries D4500 CT Hybrid Commuter Coach (Allison Ep50 EP).

- Example: BAE Systems (Endicott, NY)
  - *Selected components supplied:* AC traction drive induction motor; BAE HDS200 and HDS300 full series electric propulsion systems (aka BAE HybriDrive). Power flows in series from engine to generator to traction motor; alternator system; adaptable to all electric.
  - *Class 3-8 Applications:* Nova LFS HEV bus; Nova LFS Arctic HEV; Orion VII HEV bus; Gillig Low Floor Series Buses w/diesel-electric propulsion.

Class 3-8 HEV, EV and PHEV North American Supply Chain Players

* Companies can overlap across categories.

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Autonomous Vehicle Players: Relevant to the Future Class 3-8 Market

* Companies can overlap across categories.

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Coordination and Collaboration

- Close coordination and collaboration with 100s of industry, OEMs, Tier 1-4, universities and other subject matter experts on both public and proprietary basis.
- In-depth engagement with select sources at conferences (e.g., APEC 2018, APEC 2019, PSMA, PSMA Transportation Power Electronics Committee, IEEE) to work to identify gaps and technology development opportunities in support of VTO and USDRIVE partnership goals.
- Engagement with DOE and other federal research labs, e.g.; SP shared early data-sets on MD-HD market and component suppliers with NREL and ORNL for discussion and feedback.
- Monthly updates with VTO to exchange information, discuss interim actionable results and gather feedback on relevant research activities and data-sources.

Responses to Previous Year Reviewers' Comments

Comment	Response
Reviewer asked why an analysis of the quantity of electric trucks presently on the road is necessary? Why is the analysis not based on a future population of vehicles?	SP performs the work that VTO requests.
Not clear to the reviewer what modeling of quantitative and qualitative data entails and how this will be of overall benefit.	Modeling of data enables SP to produce new domain models (not computational), which define key data nodes, attributes and weights, which are then used to organize large qualitative and quantitative data-sets to enable ID, track, report and insight re: NA supply chain technology developments and gaps.
One reviewer stated that two year total project funding is excessive for the data requested and seen thus far in this project.	Clarification needed: Two year funding covers four (4) separate research activities: FY18 covers (1) report on AV and Connected Vehicles (issued Nov. 2017), and (2) full Class 3-8 HEV and EV research. FY19 covers (1) report on Class 3-8 HEV and EVs (released in April 2019), and (2) full NA EVSE and EV charging infrastructure research.

Summary Results

- FY18: Produced public report on AV and Connected Vehicles R&D Gaps.
  - "R&D Gap and Trend Analysis for Autonomous and Connected Vehicles: On Connectivity, Sensors and Sensor Systems," (November 2017).
- FY18: Completed Supply Chain Assessment of NA Class 3-8 HEV and EVs and their Traction Drive Component Suppliers.
  - Hundreds of 3rd party market research, company reports and studies combined, reviewed.
  - 900 unique contacts made via telephone and email.
  - 400 companies, associations and individuals with expertise in Class 3-8 HEV and EV NA supply chain identified.
  - 165 Senior Executives in Class 3-8 HEV and EV supply chain identified and contacted for interviews.
  - 165 Mid-Level Executives in Class 3-8 HEV and EV supply chain identified and contacted for interviews.
- FY19: Produced public report on Class 3-8 HEV and EV NA Supply Chain Assessment.
  - "Class 3-8 HEV and EV Vehicles Operating on North American Roads and Their Supply Chain: Focus on Drive-Train Motors, Inverters, Converters and Batteries" (April 2019).
- FY19: NA EV Charging Infrastructure supply chain research, results to-date at ~50% completion:
  - 250+ NA EV charging collection phone calls made and e-mails executed as of March 2019.
  - 1,000+ NA EV charging electronic sources reviewed as of March 2019.
  - 360+ individuals and 140+ organizations identified as having relevant experience or information regarding NA EV charging infrastructure and EVSEs as of March 2019.
  - Attended APEC 2019 (IEEE & PSMA).
  - Ongoing detailed interactions with PSMA (Power Sources Manufacturers Association) Transportation Power Electronics Committee.

Thank you for your interest.

We welcome your feedback.

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Technical Background Information

- Definitions of Class 3-8 Vehicles.

Vehicle Classifications

Class is determined by the gross vehicle weight rating (GVWR) of the vehicle.

Light Duty Trucks

- Class 1 – This class of truck has a GVWR of 0 to 6,000 pounds (0 to 2,722kg).
- Class 2 – This class of truck has a GVWR of 6,001 to 10,000 pounds (2,722 to 4,536 kg).
- Class 3 – This class of truck has a GVWR of 10,001 to 14,000 pounds (4,536 to 6,350 kg).

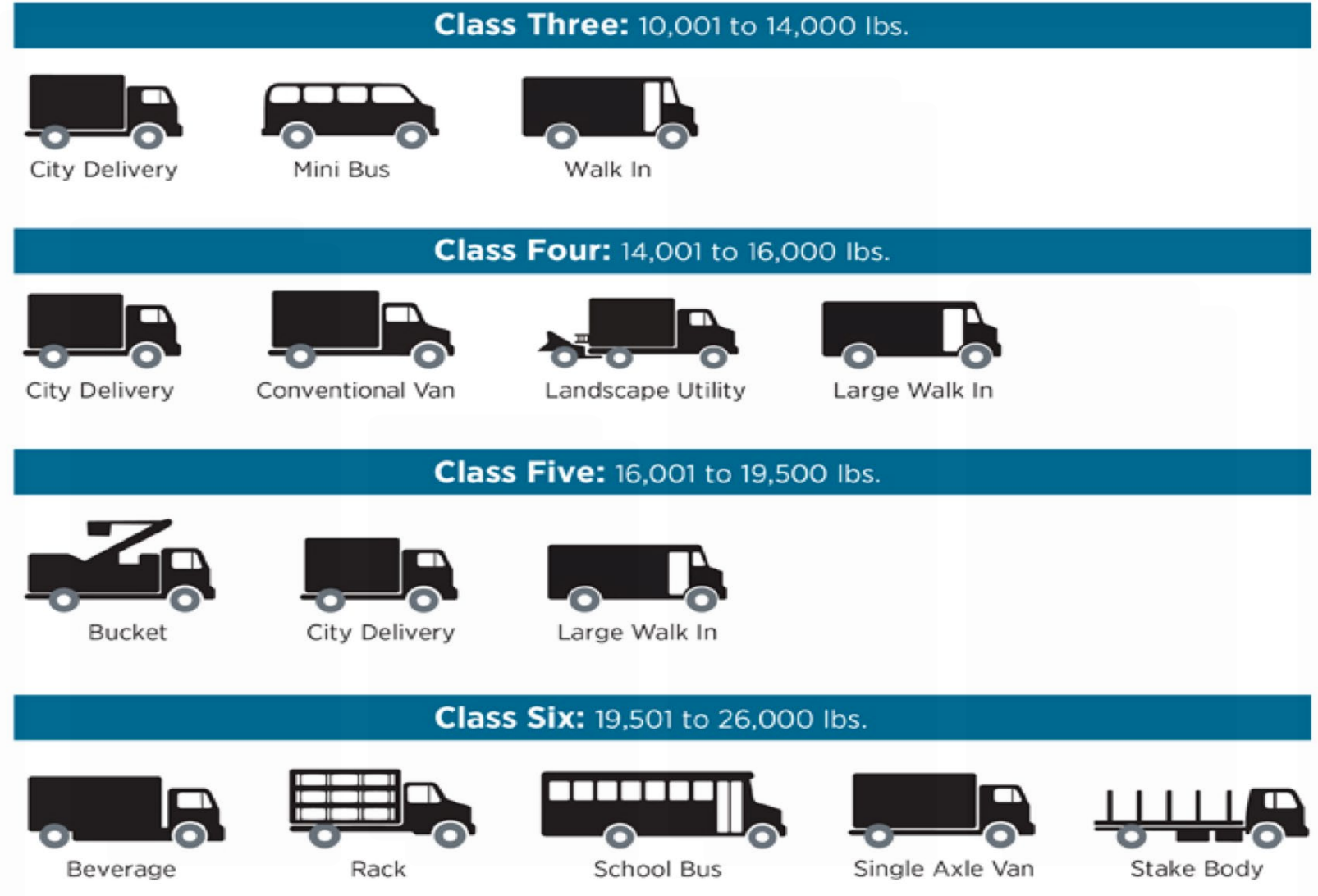
Medium Duty Trucks

- Class 4 – This class of truck has a GVWR of 14,001 to 16,000 pounds (6,351 to 7,257 kg).
- Class 5 – This class of truck has a GVWR of 16,001 to 19,500 pounds (7,258 to 8,845 kg).
- Class 6 – This class of truck has a GVWR of 19,501 to 26,000 pounds (8,846 to 11,793 kg).

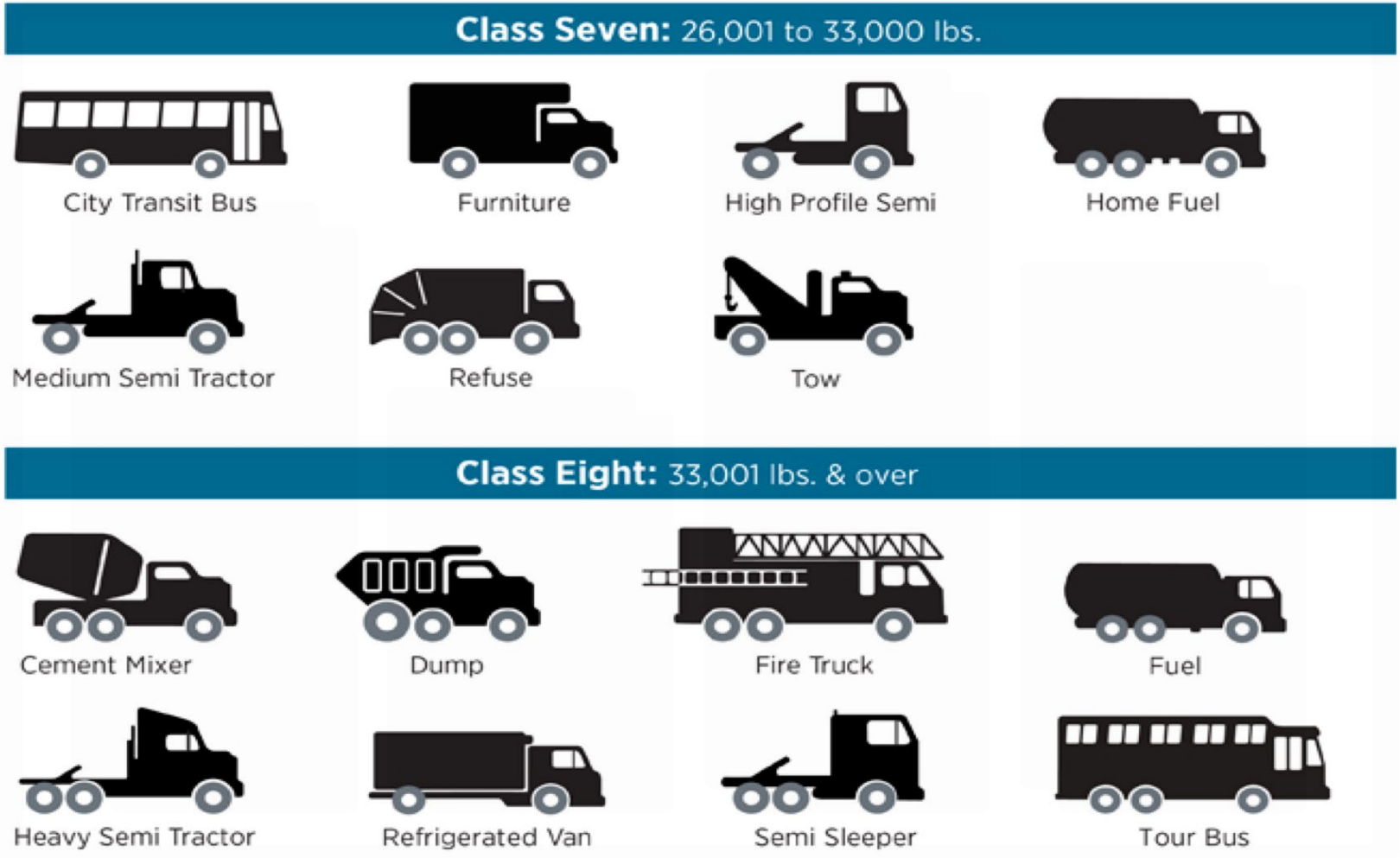
Heavy Duty Trucks

- Class 7 – This class of truck has a GVWR of 26,001 to 33,000 pounds (11,794 to 14,969 kg).
- Class 8 – This class of truck has a GVWR of greater than 33,001 pounds (14,969 kg), and includes all tractor trailers.

Source: "Commercial Motor Vehicle Classification", Martin Murray, 11-18-16, https://www.thebalance.com/commercial-motor-vehicle-classification-2221025; Accessed 10-11-17.



Source: https://www.afdc.energy.gov/data/10381; Accessed 11/16/17.



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